Structural aspects related to the vacuum vessel of the SHIP Project

Research Group at University of Naples Federico II

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Contribution on constructability issues from Construction company Castaldo spa

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Working group

University of Naples Federico II

Prof. Gaetano Manfredi
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- Structural concept and design
- Prototypes proposal for design validation
- Tests on prototypes

Castaldo Spa

Eng. Antonio Mastroberardino
Eng. Giuseppe Perrone

- Constructive method
- Execution
- Transportation
- Quality control

Reference standards for structural design and checks

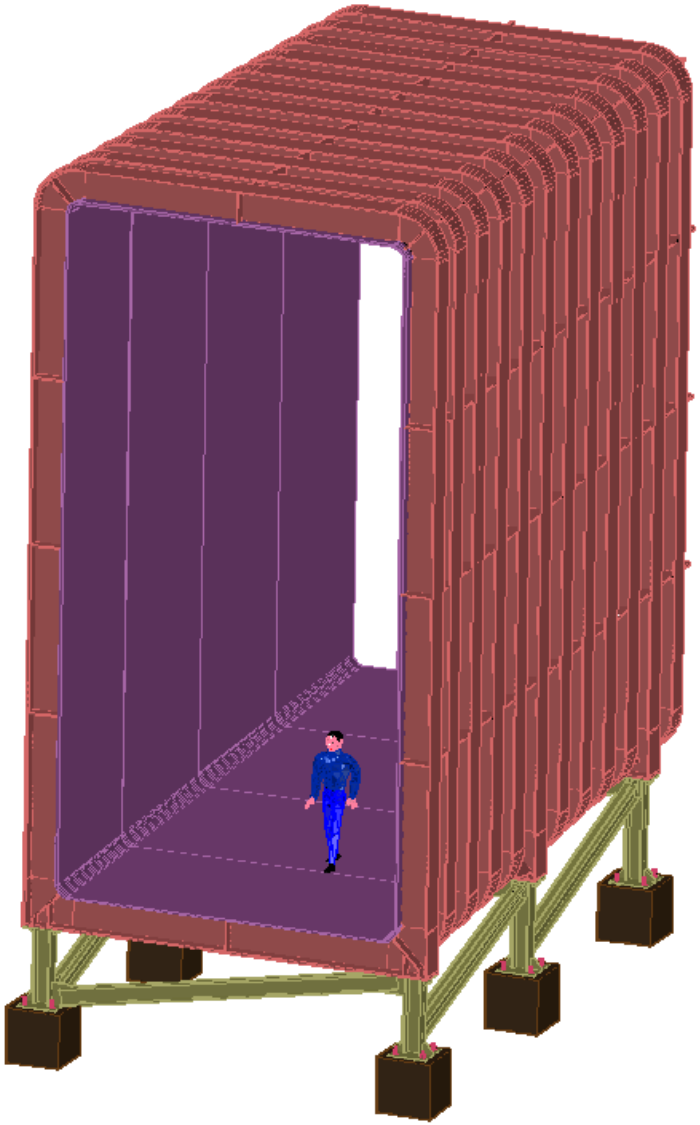
- Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings;
- Eurocode 3: Design of steel structures - Part 1-5 : Plated structural elements;
- Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings;
- NTC 2008: Italian code.

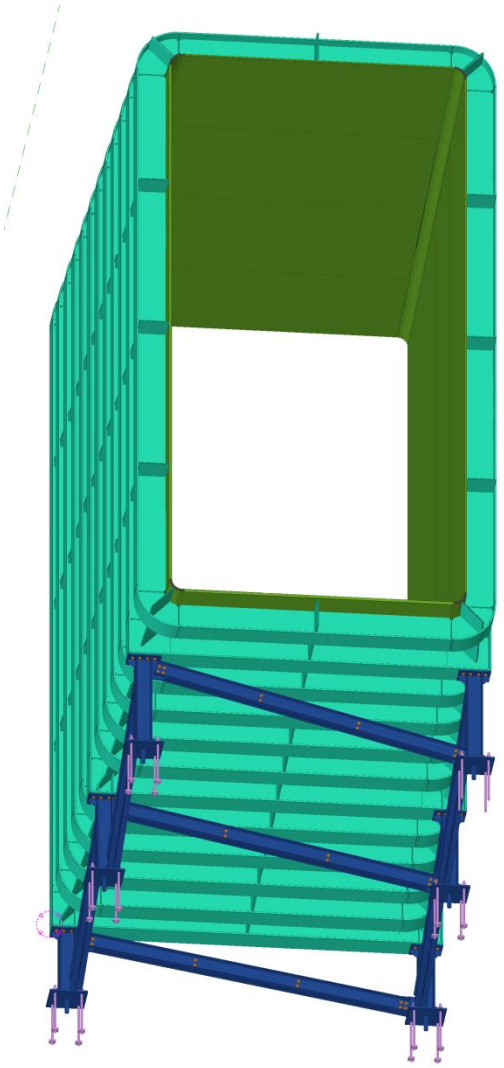
Relevant structural verification

- **Serviceability limit states:**
  - **Vertical and horizontal deflection → EC3 1-1 point 7 – Has been limited the deflection in $h_{ave}/500$. Codes typically indicate $h_{max}/L=1/200 \div 1/500$. Considering the relevance of the vacuum vessel structure, a deflection limit of 1/500 has been selected to be on the safe side.**

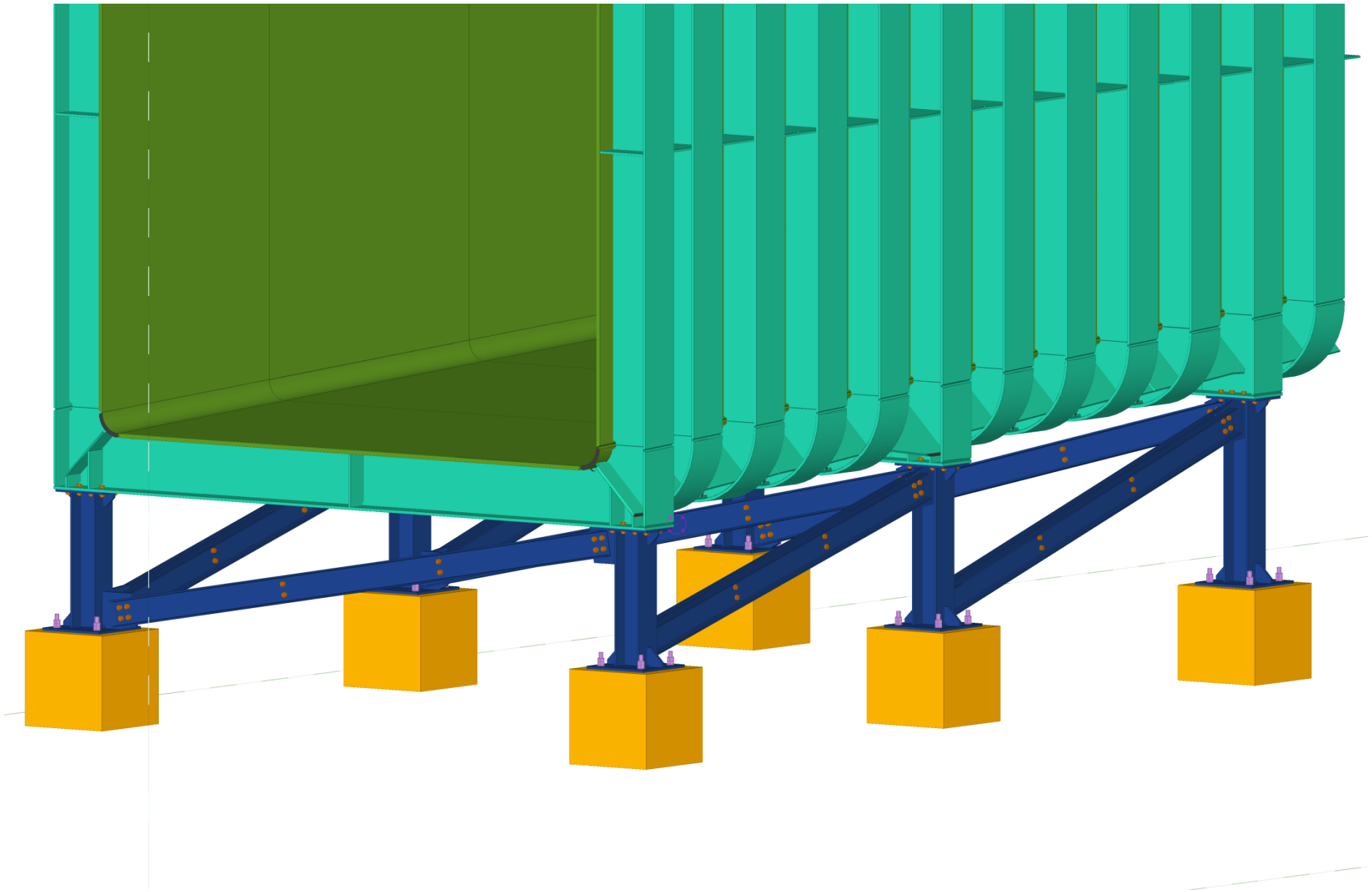
- **Ultimate limit states:**
  - **Resistance of cross-sections → EC3 1-1 point 6.2;**
  - **Buckling resistance of members → EC3 1-1 point 6.3;**
  - **Reduced stress method → EC3 1-5 point 10 – Effect of shear lag and of plate buckling;**

Construction phase – tridimensional final model

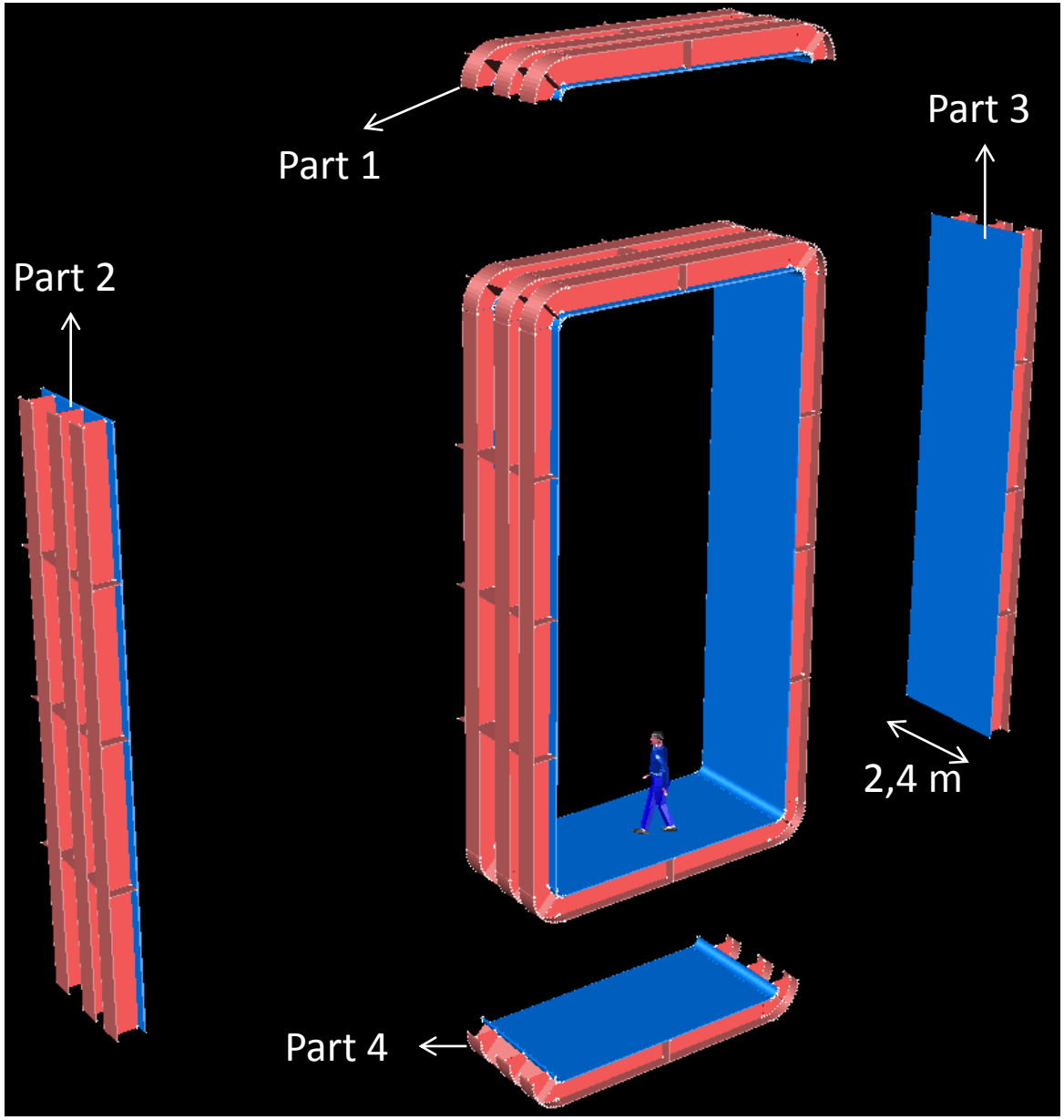




Construction phase – tridimensional final model



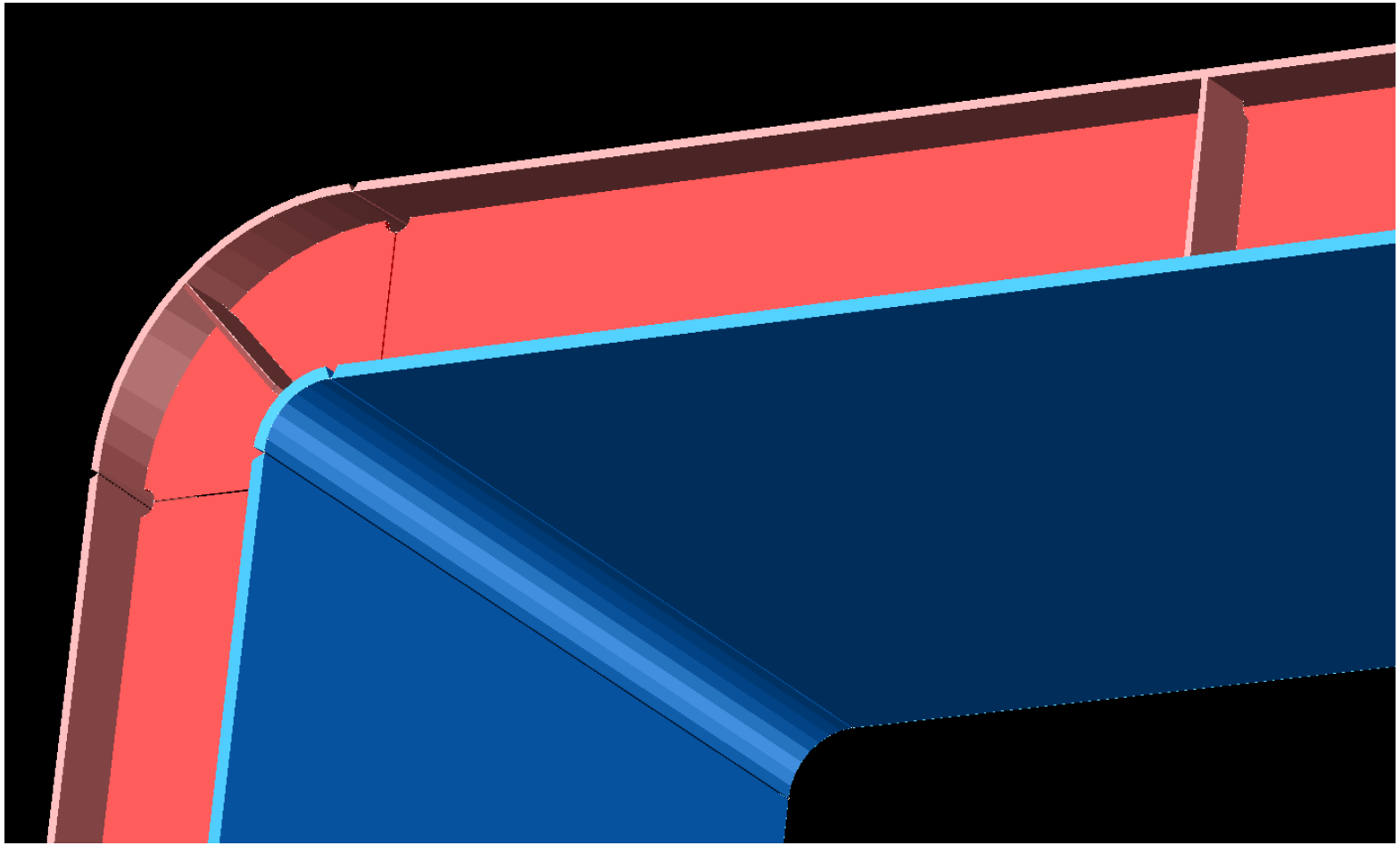
Construction phase – Basic parts



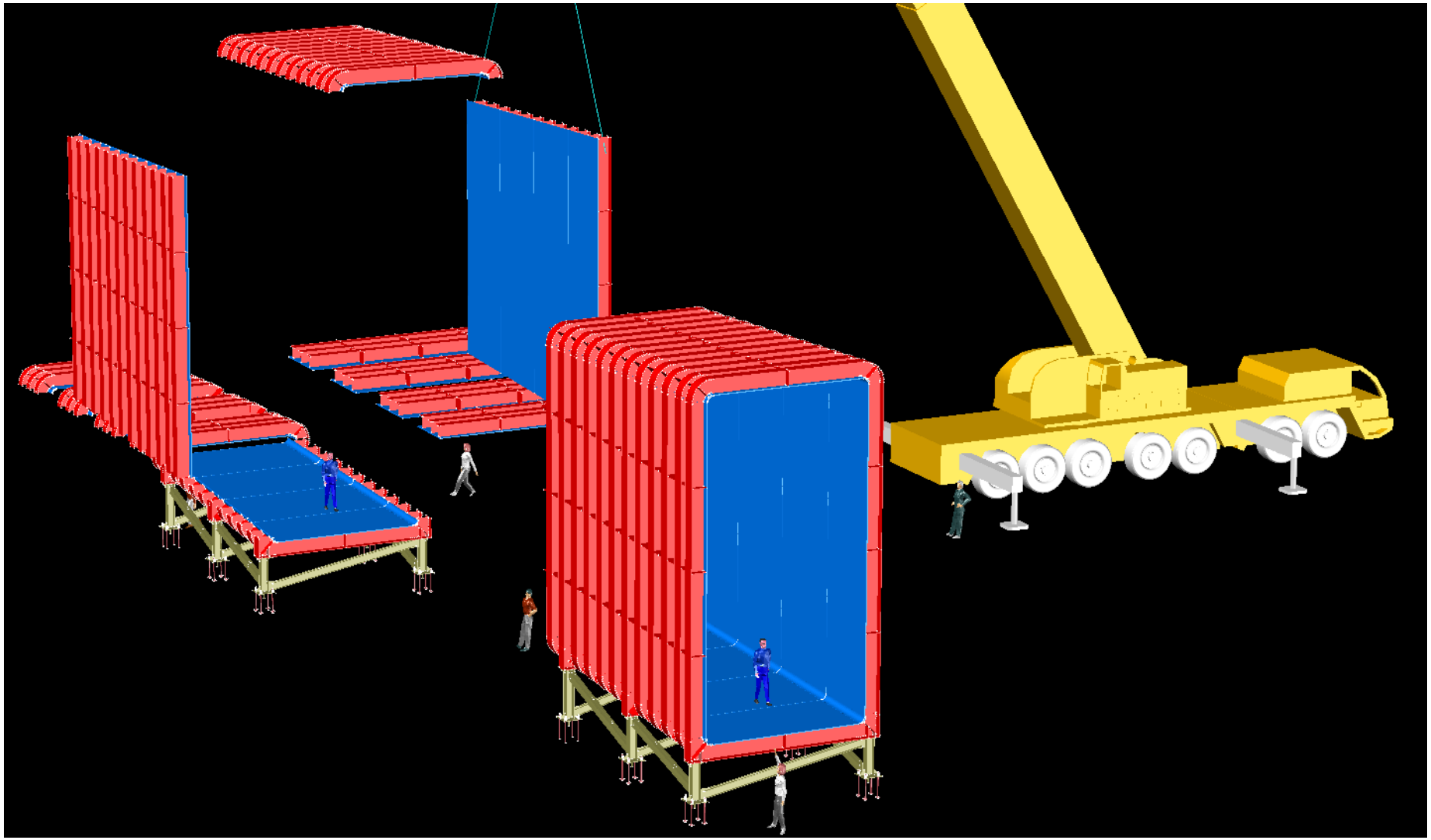
Depth of each module 2,4 m (dimension governed by transportation constraints)

Construction phase – Assembling parts

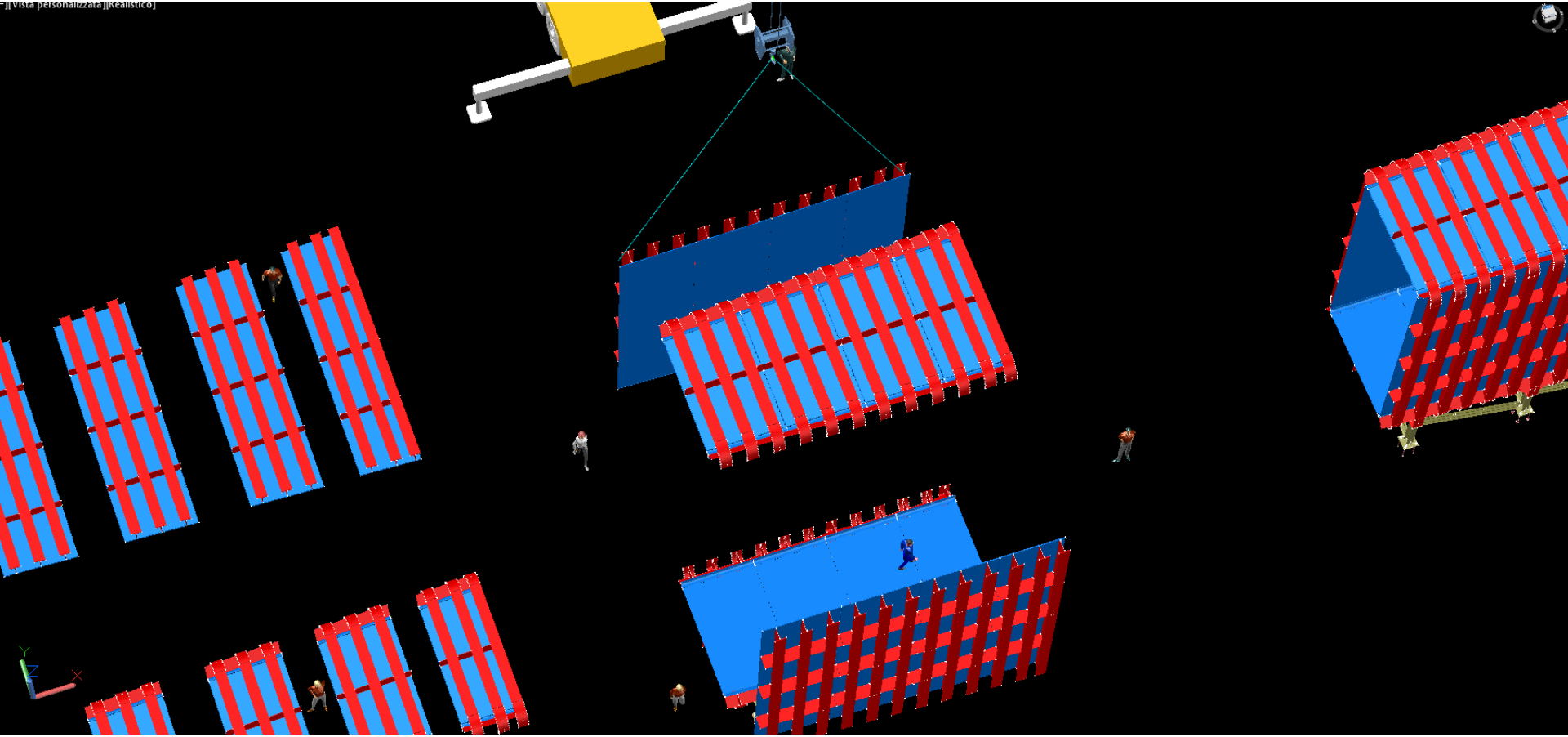
To reduce corner effects, it is proposed to round them



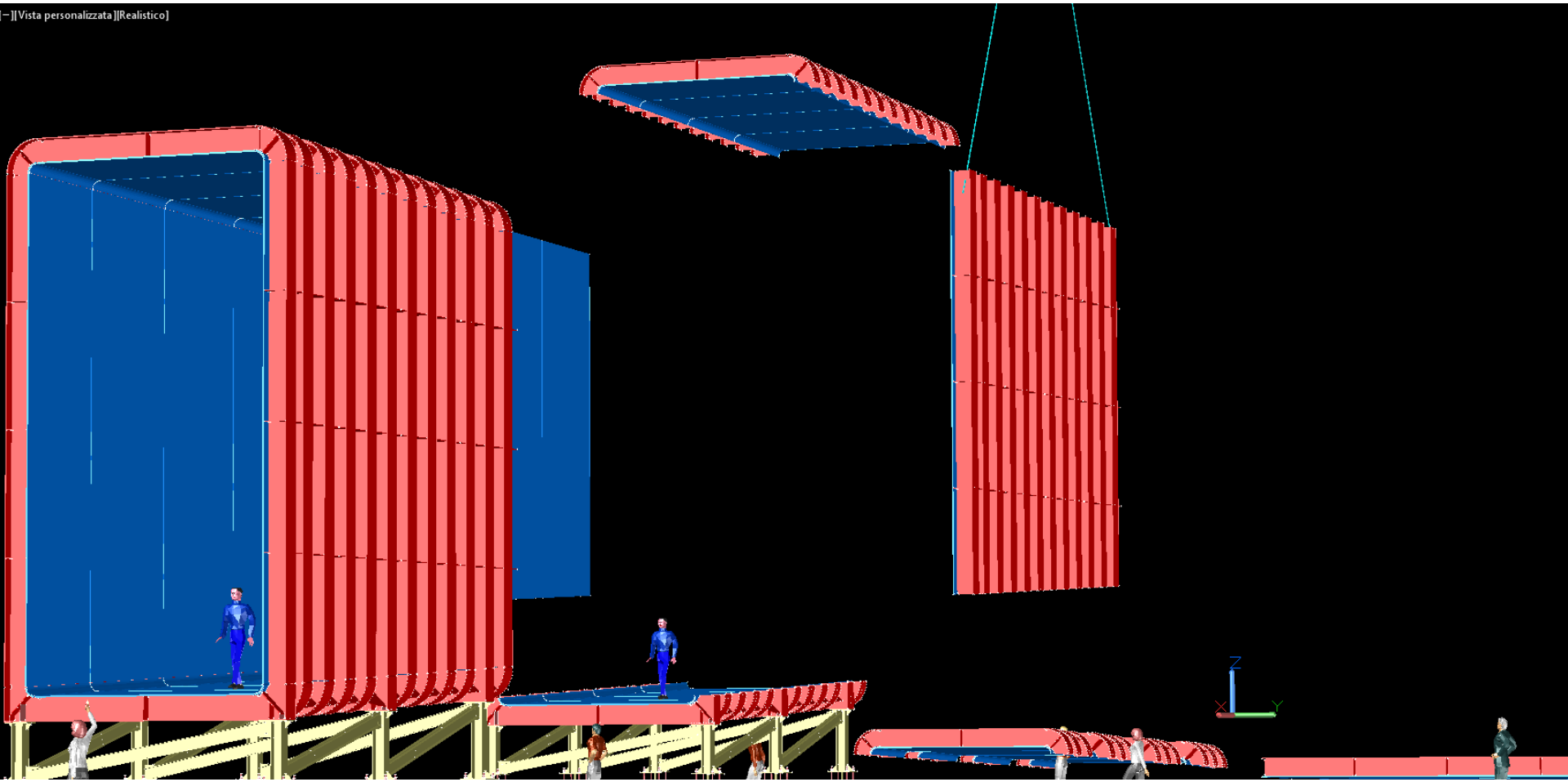
Construction phase – Assembling parts



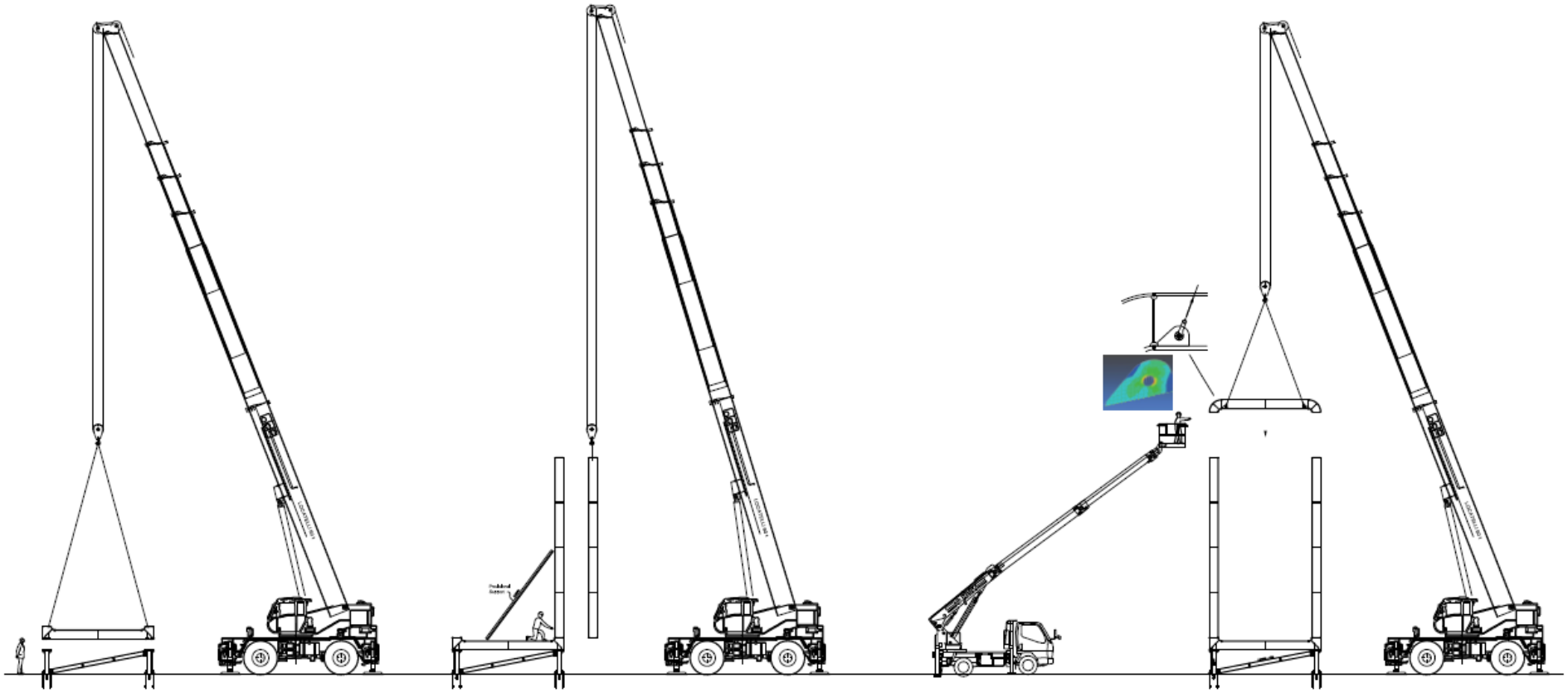
Construction phase – Assembling parts



Construction phase – Assembling parts



Construction phase – Assembling parts

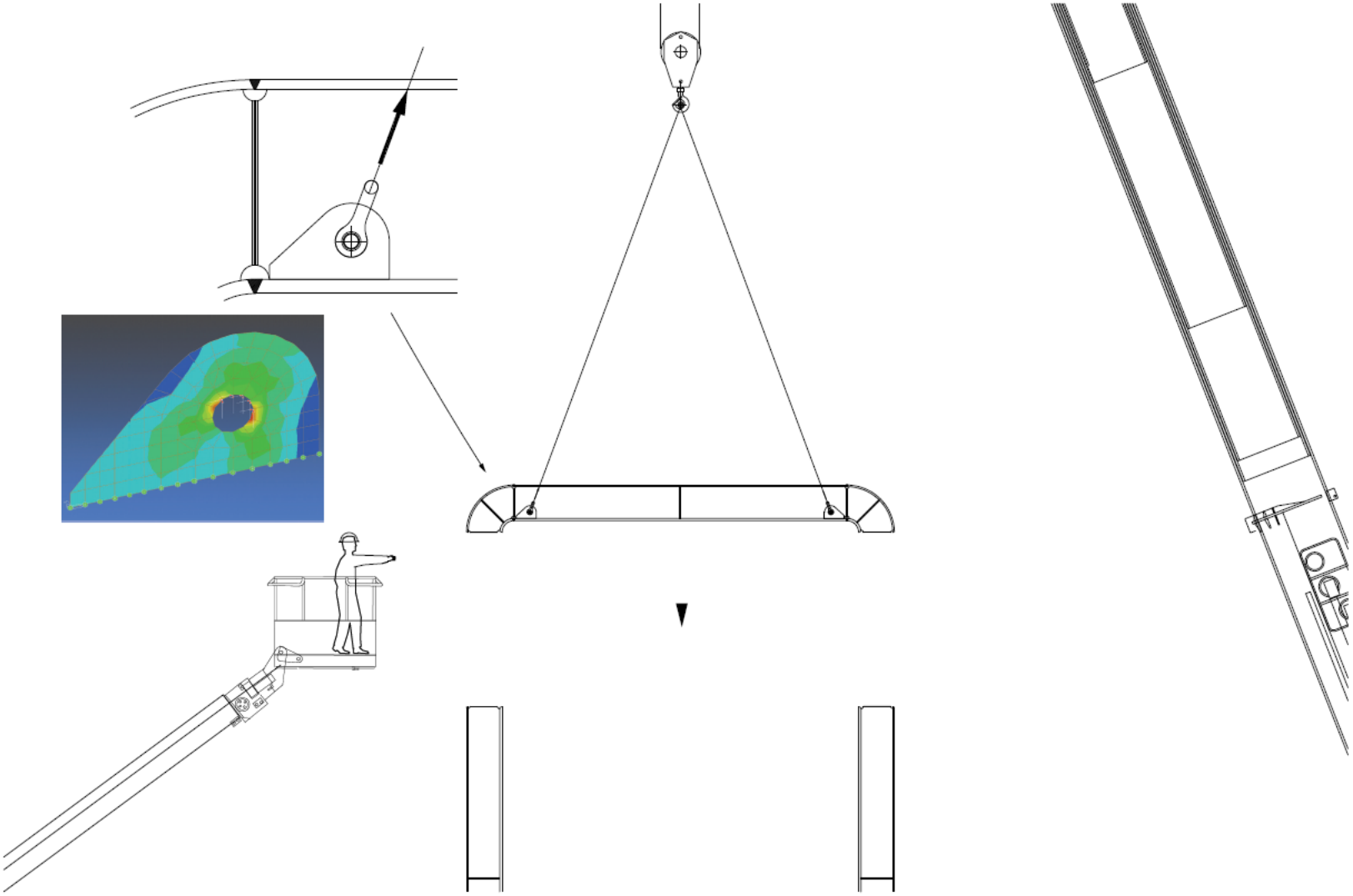


1. Bottom closure element

2. Lateral closure element

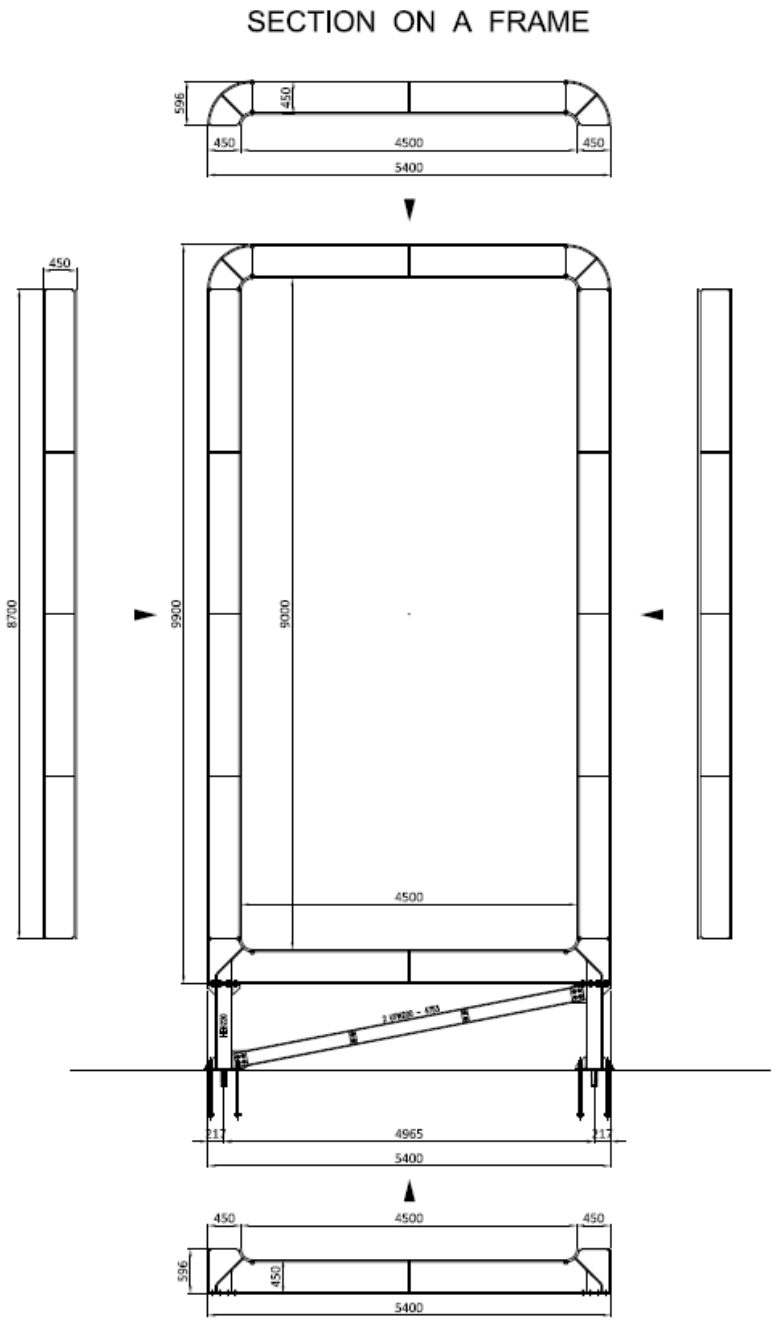
3. Top closure element

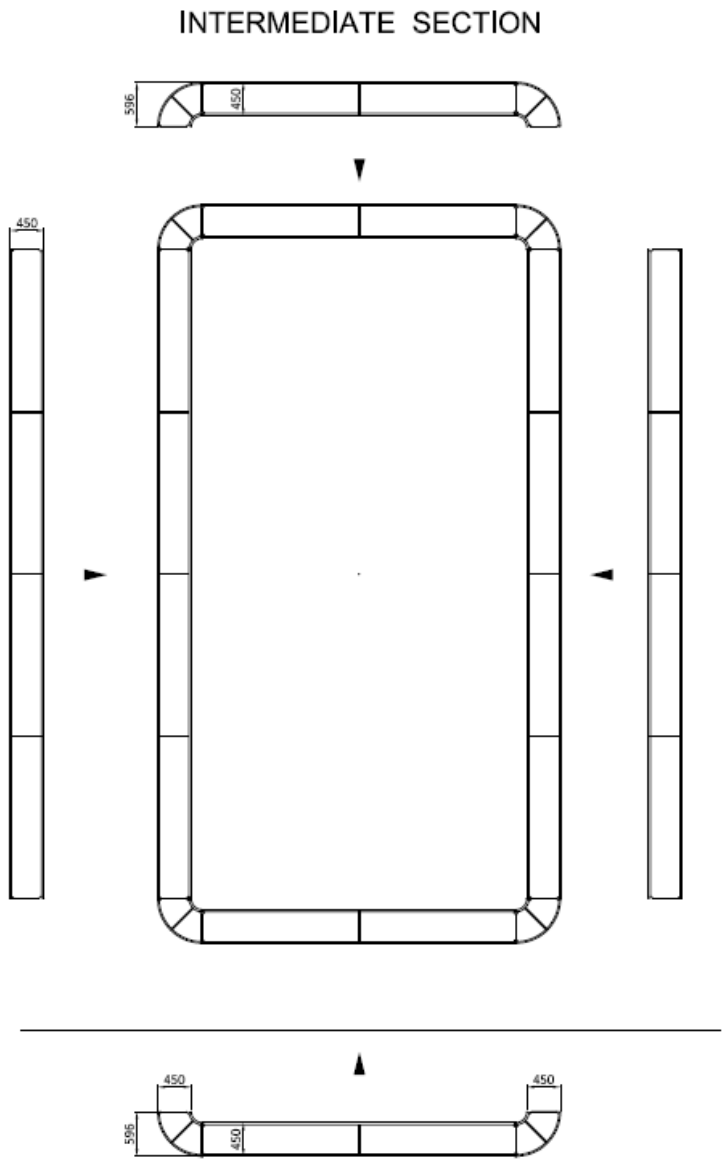
Construction phase – Assembling parts



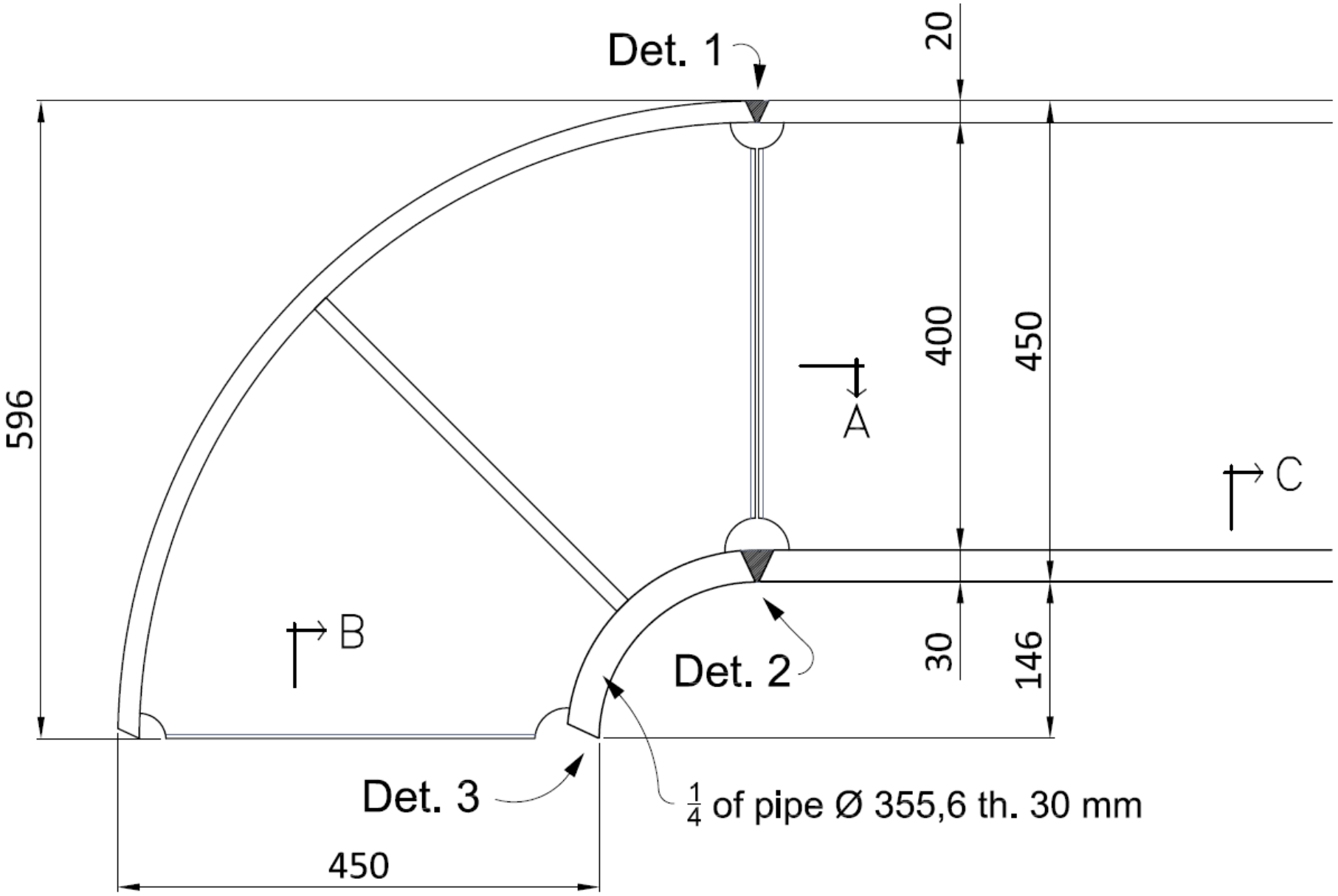
Detail of the lifting hook

Construction phase – Assembling parts





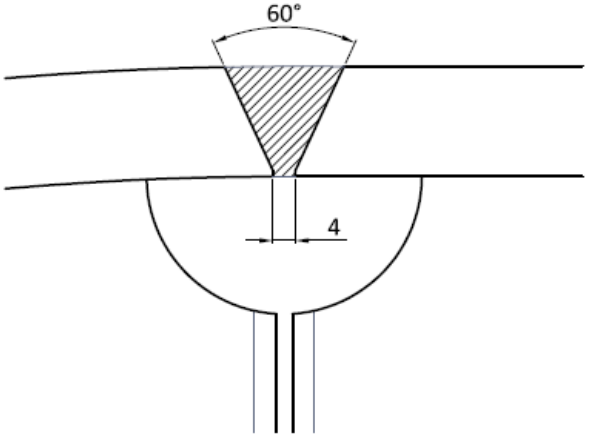
Construction phase – Welded joints



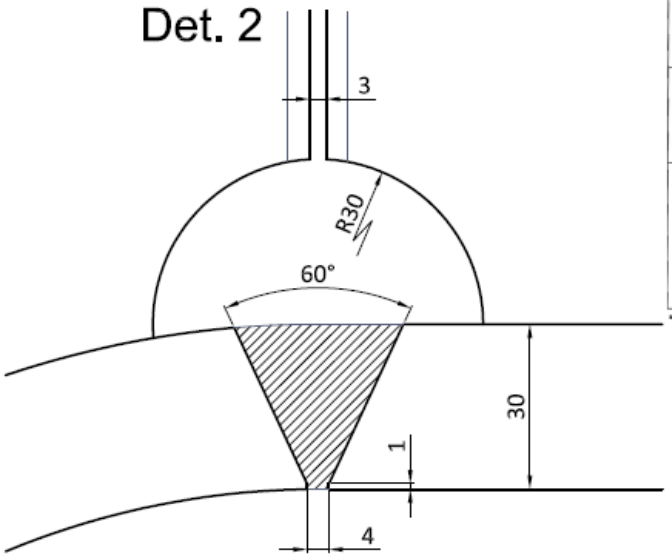
Construction phase – Welded joints

Det. 1

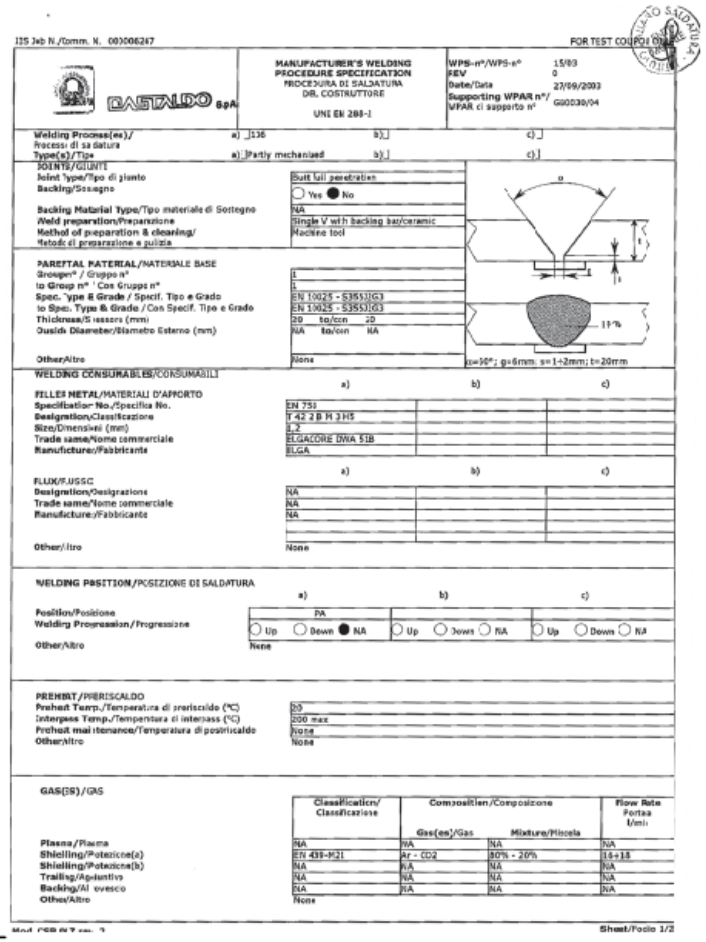
Welding in workshop
WPAR support GB0030 / 04



Det. 2



Welding in workshop
WPAR support GB0030 / 04



IIS Jeb N./Comm. N. 003006267 — FOR TEST COUPON ONLY

MANUFACTURER'S WELDING PROCEDURE SPECIFICATION
PROCEDURA DI SALDATURA DEL COSTRUTTORE
UNI EN 288-1

WPS-n°/WPS-n° 15/03
REV 0
Date/Data 27/09/2003
Supporting WPAR n°/ WPAR di supporto n° GB0030/04

Welding Process(es)/ Processi di saldatura: a) 135 b) c)
Type(s)/Tipo: a) Partly mechanized b) c)

JOINTS/GIUNTI
Joint Type/Tipo di giunto: Butt full penetration
Backing/Sostegno: ○ Yes ● No
Backing Material Type/Tipo materiale di Sostegno: NA
Weld preparation/Preparazione: Single V with backing bar/ceramic
Method of preparation & cleaning/ Metodo di preparazione e pulizia: Machine tool

PARENTAL MATERIAL/MATERIALE BASE
Groupe° / Gruppo n°: 1
to Group n° / Con Gruppo n°: 1
Spec. Type & Grade / Specif. Tipo e Grado: EN 10025 - S355JG3
to Spec. Type & Grade / Con Specif. Tipo e Grado: EN 10025 - S355JG3
Thickness/Spessore (mm): 20 to/con 20
Ouside Diameter/Diametro Esterno (mm): NA to/con NA
Other/Altro: None

α=90°; g=6mm; s=1÷2mm; t=20mm

WELDING CONSUMABLES/CONSUMABILI

FILLER METAL/MATERIALI D'APPORTO	a)	b)	c)
Specification No./Specifica No.	EN 756		
Designation/Classificazione	T 42 2 B M 3 H5		
Size/Dimensioni (mm)	1,2		
Trade name/Nome commerciale	ELGACORE DWA 51B		
Manufacturer/Fabbricante	ELGA		

FLUX/FLUSSO	a)	b)	c)
Designation/Designazione	NA		
Trade name/Nome commerciale	NA		
Manufacturer/Fabbricante	NA		
Other/Altro	None		

WELDING POSITION/POSIZIONE DI SALDATURA

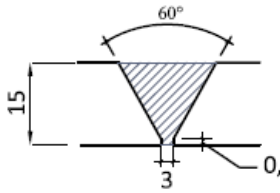
	a)	b)	c)
Position/Posizione	PA		
Welding Progression/Progressione	○ Up ○ Down ● NA	○ Up ○ Down ○ NA	○ Up ○ Down ○ NA
Other/Altro	None		

PREHEAT/PRERISCALDO
Preheat Temp./Temperatura di preriscaldo (°C): 20
Interpass Temp./Temperatura di interpass (°C): 200 max
Preheat maintenance/Temperatura di postriscaldo: None
Other/Altro: None

GAS(ES)/GAS

	Classification/ Classificazione	Composition/Composizione		Flow Rate Portata l/mi
		Gas(es)/Gas	Mixture/Miscela	
Plasma/Plasma	NA	NA	NA	NA
Shielding/Protezione(a)	EN 439-M21	Ar - CO2	80% - 20%	16÷18
Shielding/Protezione(b)	NA	NA	NA	NA
Trailing/Ausiliario	NA	NA	NA	NA
Backing/Al rovescio	NA	NA	NA	NA
Other/Altro	None			

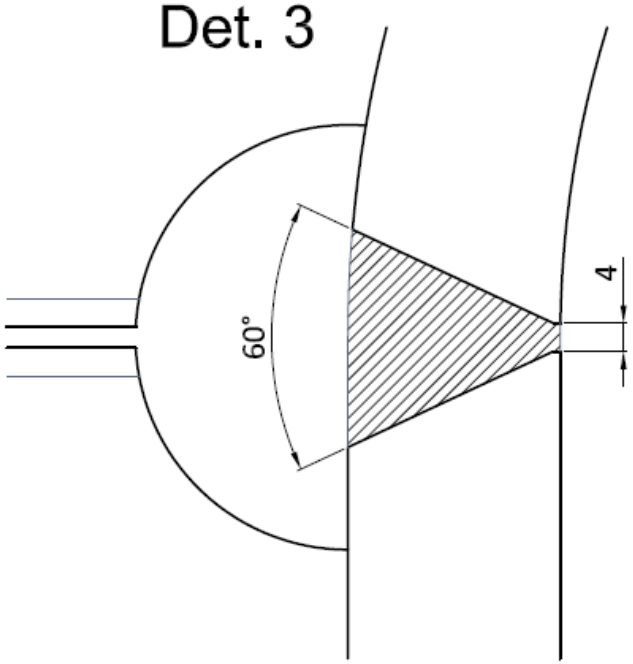
Mod. CSB 07 rev. 2 — Sheet/Foglio 1/2



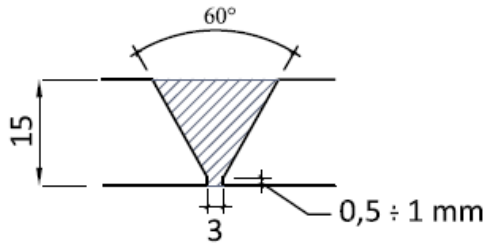
Section "A"

Welding in workshop
WPAR support GB0030 / 04

Construction phase – Welded joints



Welding carried out on site
WPAR support GB0067 / 07



Welding carried out on site
WPAR support GB0067 / 07

IIS Job/Comm N° 000015518 — Sheet/Foglio 2/5

Istituto Italiano della Saldatura ENTE MORALE

WELDING PROCEDURE QUALIFICATION RECORD
QUALIFICA DI PROCEDIMENTO WPQR

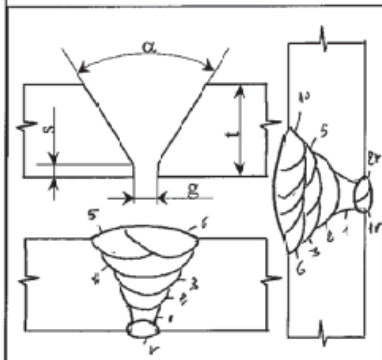
WPQR-N./CERT. N.	GB0067/07
WPS N./PROC	CASTALDO 62/06 and 63/06
WPS rev./ PROC rev	0

Welding Proc. Approval Record/Qualifica di proc.	GB0067/07	Examiner Body/Ente Esamin.	IIS
WPS N./Proc	CASTALDO 62/06 and 63/06	Rev. 0	Date/Data 04/10/2006

Welding Process(es)/Processo(i) di saldatura	a) 136	b)		c)	
Types/Tipi (Man. Partly mech. etc)	a) Partly mechanized	b)		c)	

Joint Type/Tipo di giunto: Butt full penetration welded from both sides
Backing/Sostegno: ○ Yes ● No
Backing Material Type/Tipo materiale di Sostegno: NA

Joint Design and Welding Sequences



α= 60°; t=20 mm; g=3 mm; s=1,0 mm

Runs or layers Passate o strati	Welding Process Proc. Saldatura	Filler metal Materiale d'apporto Size/Dim. (mm)		Welding current Corr. di sald. A	Voltage Tensione V	Travel Speed Velocità Sald. mm/min	Heat Input Apporto Termico kJ/mm
		1E	2E	1E÷2E	1E÷2E		
1(PC)	136	1,2		230	23	280	0,904
2	136	1,2		230	23	300	0,848
3-2r	136	1,2		230	23	300	0,848
3÷10	136	1,2		270	26	260	1,296
1(PF)	136	1,2		150	19	150	0,912
2	136	1,2		150	19	160	0,856
r	136	1,2		220	22	160	1,456
3÷6	136	1,2		250	23	170	1,624

PARENT MATERIAL/MATERIALE DI BASE

Spec. Type & Grade/Specifica Tipo e Grado	EN 10025-5	S355J0W+AR
to Spec. Type & Grade/a Specifica Tipo e Grado	EN 10025-5	S355J0W+AR
Group No./Gruppo to/al Group No./Gruppo	1.4 to/con 1.4	
Thickness of test piece/Spessore del saggio (mm)	20 to/con 20	
Outside diameter of test piece/Diametro esterno del saggio (mm)	NA to/con NA	
Other/Altro:	NONE	

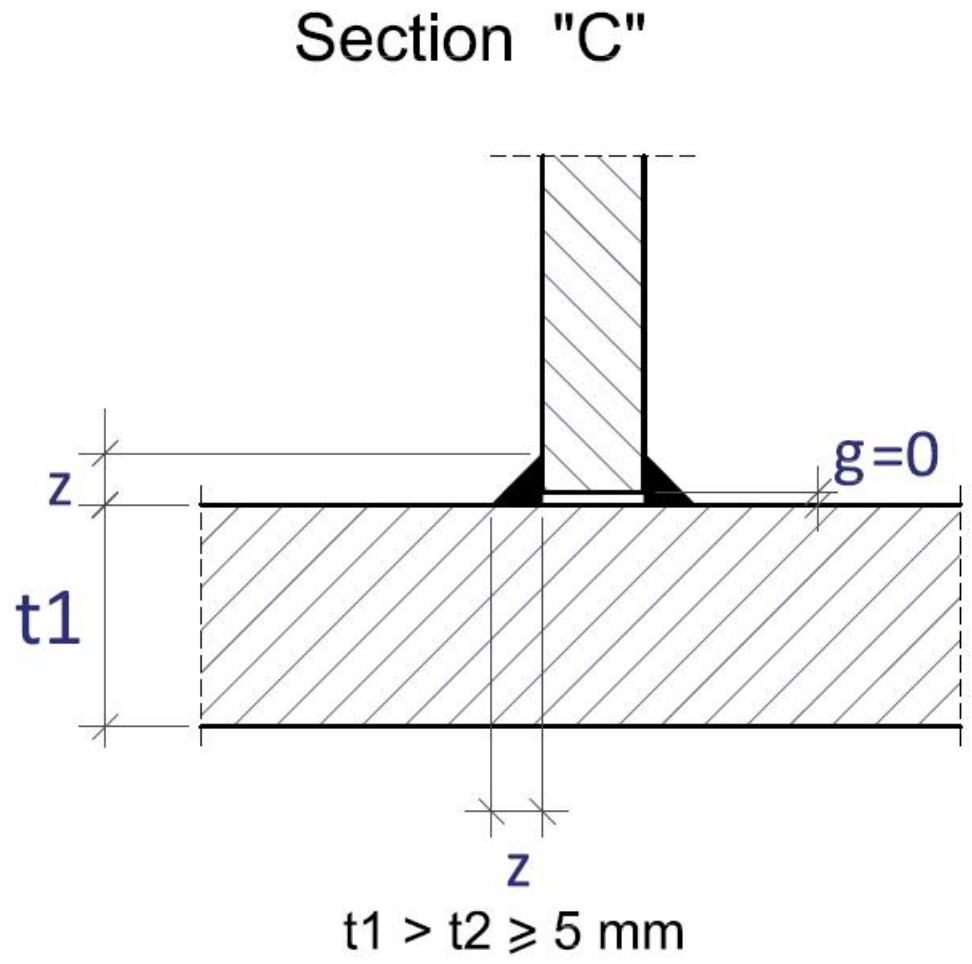
WELDING CONSUMABLES/CONSUMABILI

	a)	b)	c)
FILLER METAL/MATERIALI D'APPORTO			
Specification No./Specifica No.	None		
Designation/Classificazione	None		
Size/Dimensioni (mm)	1,2		
Trade name/Nome commerciale	ETC 6149R		
Manufacturer/Fabbricante	ETC		

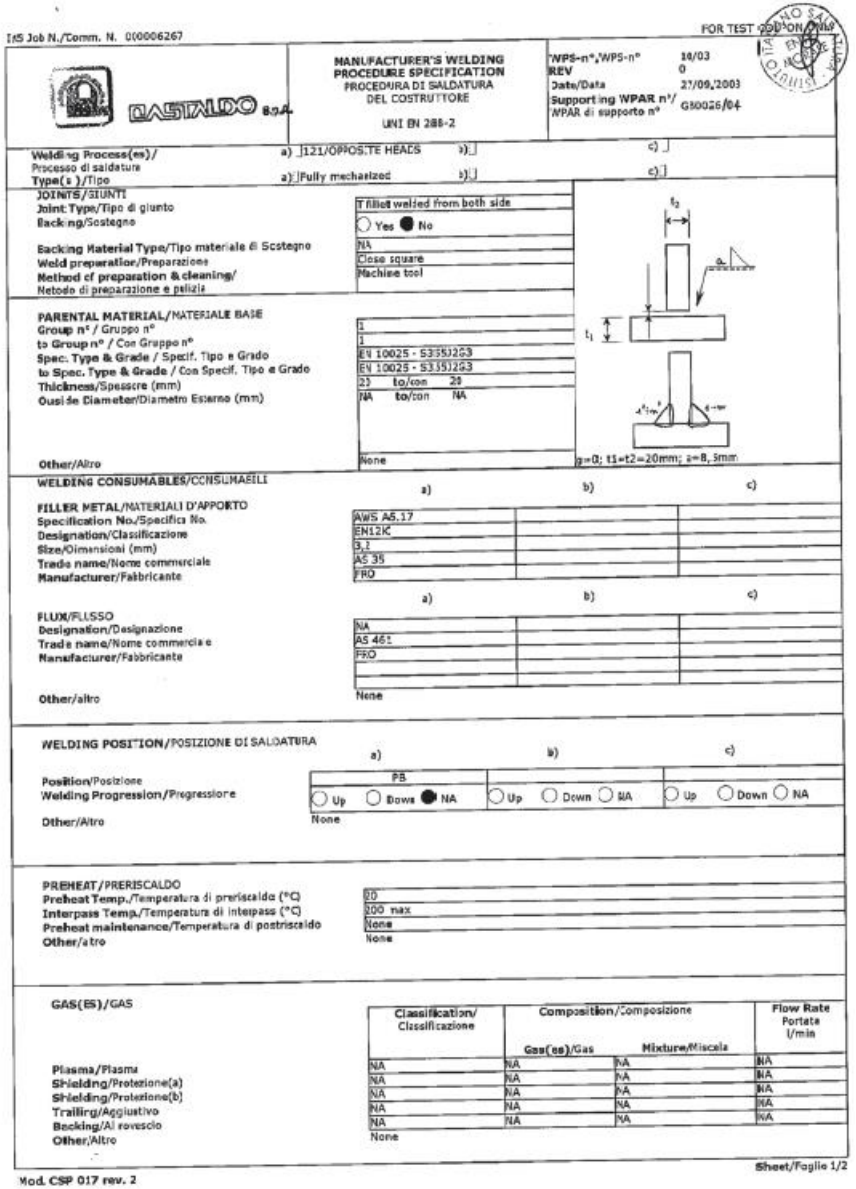
	a)	b)	c)
FLUX/FLUSSO			
Designation/Designazione	NA		
Trade name/Nome commerciale	NA		
Manufacturer/Fabbricante	NA		
Other/altro	NONE		

Mod. CSP 044 rev. 0

Construction phase – Welded joints



Welding in workshop
WPAR support GB0026 / 04



IdS Job N./Comm. N. 000006267

FOR TEST PURPOSES ONLY

CASTALDO S.p.A.

MANUFACTURER'S WELDING PROCEDURE SPECIFICATION
PROCEDURA DI SALDATURA DEL COSTRUTTORE
UNI EN 288-2

WPS-n°/WPS-n° 10/03
REV 0
Date/Data 27/09/2003
Supporting WPAR n°/ WPAR di supporto n° GB0026/04

Welding Process(es)/ Processo di saldatura: a) 121/OPPOSITE HEADS b) c)
Type(s)/Tipo: a) Fully mechanized b) c)

JOINTS/GIUNTI
Joint Type/Tipo di giunto: T fillet welded from both side
Backing/Sostegno: ○ Yes ● No
Backing Material Type/Tipo materiale di Sostegno: NA
Weld preparation/Preparazione: Close square
Method of preparation & cleaning/ Metodo di preparazione e pulizia: Machine tool

PARENTAL MATERIAL/MATERIALE BASE
Group n° / Gruppo n°: 1
to Group n° / Con Gruppo n°: 1
Spec. Type & Grade / Specif. Tipo e Grado: EN 10025 - S355J2G3
to Spec. Type & Grade / Con Specif. Tipo e Grado: EN 10025 - S355J2G3
Thickness/Spessore (mm): 23 to/con 29
Ouside Diameter/Diametro Esterno (mm): NA to/con NA
Other/Altro: None

WELDING CONSUMABLES/CONSUMABILI

FILLER METAL/MATERIALI D'APPORTO	a)	b)	c)
Specification No./Specifica No.	AWS A5.17		
Designation/Classificazione	EN12IC		
Size/Dimensioni (mm)	3,2		
Trade name/Nome commerciale	AS 35		
Manufacturer/Fabbricante	FRO		

FLUX/FLUSSO	a)	b)	c)
Designation/Designazione	NA		
Trade name/Nome commerciale	AS 461		
Manufacturer/Fabbricante	FRO		

Other/altro: None

WELDING POSITION/POSIZIONE DI SALDATURA

	a)	b)	c)
Position/Posizione	PB		
Welding Progression/Progressione	○ Up ○ Down ● NA	○ Up ○ Down ○ NA	○ Up ○ Down ○ NA

Other/Altro: None

PREHEAT/PRERISCALDO
Preheat Temp./Temperatura di preriscaldo (°C): 10
Interpass Temp./Temperatura di interpasso (°C): 200 max
Preheat maintenance/Temperatura di postriscaldo: None
Other/altro: None

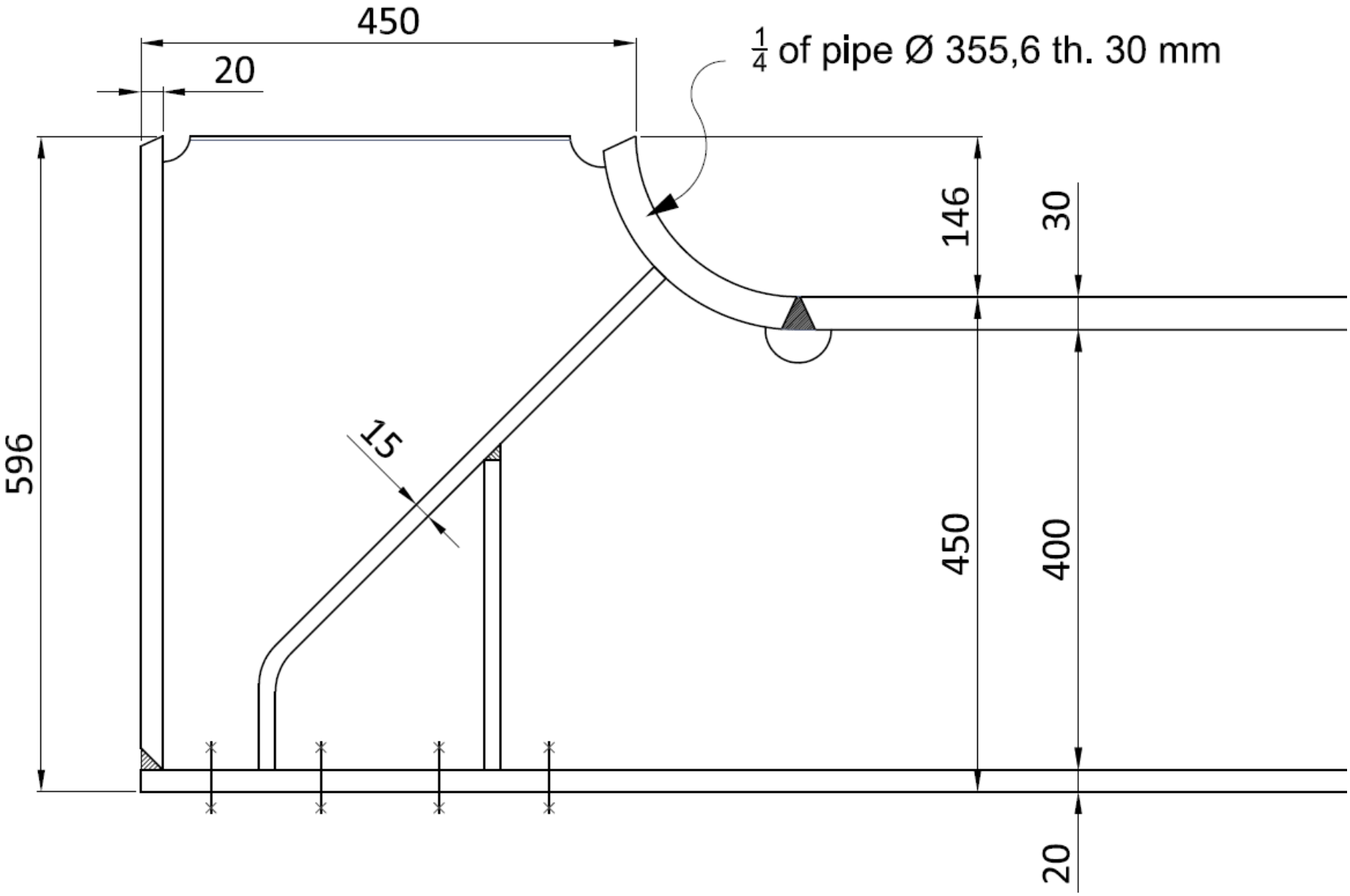
GAS(ES)/GAS

	Classification/ Classificazione	Composition/Composizione Gas(es)/Gas	Composition/Composizione Mixture/Miscela	Flow Rate Portata l/min
Plasma/Plasma	NA	NA	NA	NA
Shielding/Protezione(a)	NA	NA	NA	NA
Shielding/Protezione(b)	NA	NA	NA	NA
Trailing/Aggiuntivo	NA	NA	NA	NA
Backing/Al rovescio	NA	NA	NA	NA
Other/Altro	None			

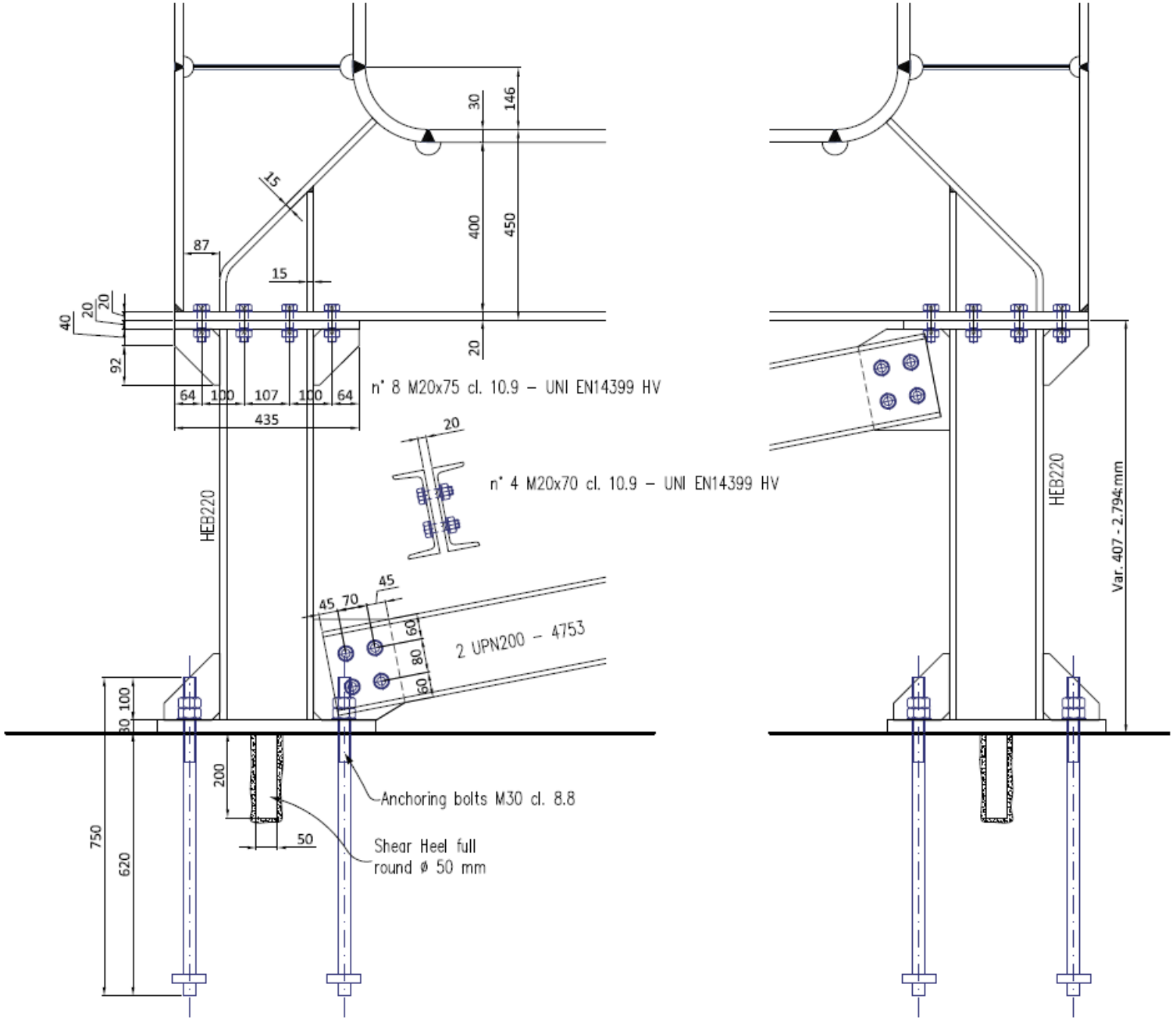
Mod. CSP 017 rev. 2

Sheet/Foglio 1/2

Construction phase – Welded joints



Construction phase – Bolted joints



Prototype proposal

- Static test (reduced scale or in real scale):
  - Bending moment test and tensile strenght test on portion assembled in workshop and in situ;
  - Test on cross-section of vessel under Serviceability condition for a long time.

- Dynamic tests:
  - Shaking table test on a reduced scale prototype (max dimensions: length=3,0 m; Width=2,4 m; Height=4,0 m).

Main Laboratory Equipment – Static test

Universal machine, height between 0,4 m and e 4,2 m.
Actuator in displacement (max displacement +/- 75 mm) or load control (max load in compression 3000 kN, in tension 2400 kN).

Tipi di test:

- **Compressione;**
- **Trazione;**
- **Flessione.**

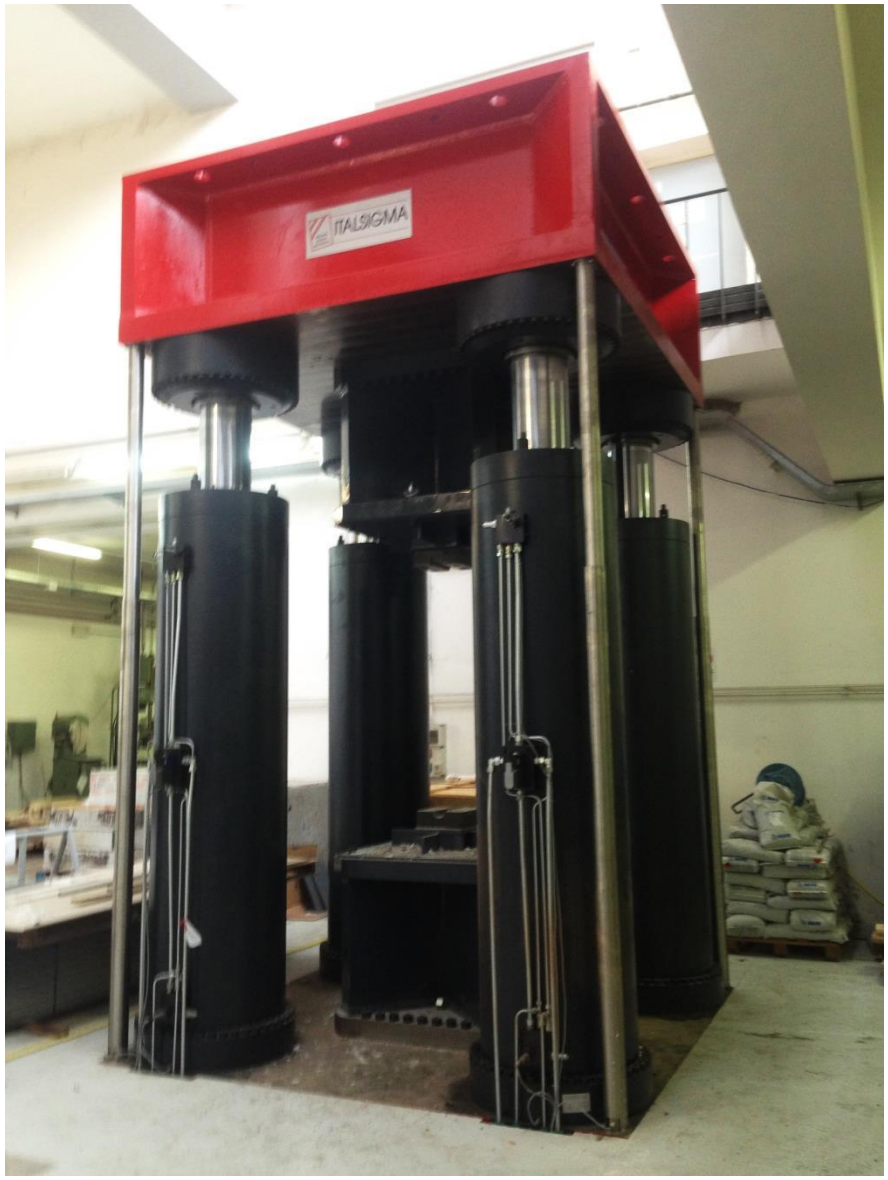
Main Laboratory Equipment – Static test

Universal MTS810 for tension, compression, cyclic and fatigue tests on samples with maximum height of 1,4 m, in load control (max load +/- 500 kN) or displacement control (max displacement +/- 75 mm).

Tipi di test:

- **Compressione;**
- **Trazione.**

Main Laboratory Equipment – Static test



Universal machine, height from 1.5 up to 4.8 m.
Actuator in displacement (max displacement +/- 125 mm) or load control (max load in compression 30,000 kN, in tension 20,000 kN).

Tipi di test:

- **Compressione;**
- **Trazione;**
- **Flessione.**

Main Laboratory Equipment
Shaking tables

DOF	2 each table
Dimension	3,0 m x 3,0 m
Max payload	20 t
Acceleration peak	1,0 g
Weight for one table	63 t
Displacement peak	± 250 mm each axis
Bandwidth	0÷50 Hz

THE TABLES SYSTEM CAN WORK IN A INDEPENDENT WAY OR CAN BE COMBINED TO FORM ONE BIG TABLE (3 m x 7 m)

Prototype of bridge piers across a fault

CLOSED SYSTEM = ACTUATORS AND SERVOVALVES INSIDE

POSSIBILITY OF MOTION